

Endpoints of invariant mass distribution in SUSY particle decays into massive particles

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Abstract

Kinematic limits on an invariant mass distribution of bc -pairs for a three-step decay chain $A \rightarrow bB \rightarrow bcC$ involving all massive particles are found. It is shown that an application of these limits to a stop quark production at the LHC could reduce significantly Standard Model background contribution.

It was shown [1]-[12] that the endpoint method could be very useful in SUSY particle mass reconstruction to find relations between masses of SUSY particles involved in a decay chain and to determine their masses. This method allows mass reconstruction without relying on a specific SUSY model. In particular the endpoint method can be applied to the decay chain

$$A \rightarrow bB \rightarrow bcC. \quad (1)$$

where particles A, B, C are invisible but particles b and c can be either detected or reconstructed and are considered as visible.

This decay chain (1) is shown in Fig. 1

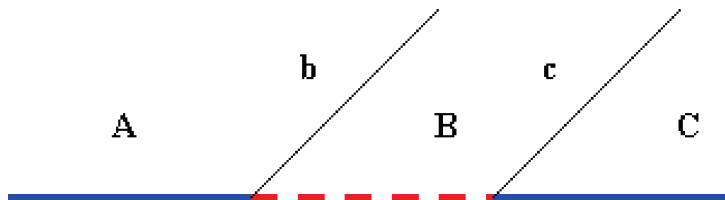


Figure 1: A cascade decay chain.

In literature, kinematic limits on an invariant mass distribution of bc-pairs in decay (1) over a variable $q^2 = (p_b + p_c)^2$ often are given for a case when at least one of visible particles is massless. However, in some cases both particles b and c can have non-negligible mass. For example, this is the case when a gluino decays into a stop quark and top quark [13],[14]. We derived these kinematic limits for the case of all massive particles in process (1) and we found

$$q = \sqrt{[-R \pm \sqrt{R^2 - 4QS}]/2Q}, \quad (2)$$

$$Q = M_B^2, \quad (3)$$

$$R = (m_b^2 - M_A^2 - M_B^2)(m_b^2 + m_c^2) + (m_b^2 - M_A^2 + M_B^2)(M_B^2 - m_b^2 - M_C^2), \quad (4)$$

$$S = M_A^2(m_b^2 - m_c^2)^2 + (M_A^2 - M_C^2)(m_b^2(M_B^2 - m_b^2 - M_C^2) + m_c^2(M_A^2 + m_b^2 - M_B^2)), \quad (5)$$

where an upper edge corresponds to the case when b and c particles are moving in opposite directions in the rest frame of particle A and a lower edge corresponds to the case when b and c particles are moving in the same direction. A nonzero lower limit is a consequence of nonzero masses of particles. Note that a similar formula can be found in [15] or obtained from Eqs.(E.9),(E.10) of [16].

In order to demonstrate the possibility of using these kinematic edges for a background suppression we consider a stop quark production in gluino decay

$$\tilde{g} \rightarrow \tilde{t}_1 t \rightarrow \tilde{\chi}_2^0 t t. \quad (6)$$

where $\tilde{\chi}_2^0$ decays into $\tilde{l}_R l \rightarrow \tilde{\chi}_1^0 l l$.

The study of sleptons and squarks of third generation is of special interest. Their masses can be very different than those of sparticles of the first and second generation, because of the effects of large Yukawa and soft couplings in the renormalization group equations. Furthermore, they can show large mixing in pairs $(\tilde{t}_L, \tilde{t}_R)$, $(\tilde{b}_L, \tilde{b}_R)$ and $(\tilde{\tau}_L, \tilde{\tau}_R)$.

For this study we choose the SU3 model point. The bulk point SU3 is the official benchmark point of the ATLAS collaboration at the LHC and it is in agreement with the recent precision WMAP data [17]. This model point is described by the set of mSUGRA parameters given in Table 1.

Point	m_0	$m_{1/2}$	A_0	$\tan\beta$	μ
SU3	100 GeV	300 GeV	-300 GeV	6	> 0

Table 1: mSUGRA parameters for the SU3 point.

The possibilities for a stop quark reconstruction in different decay chains and for different points in the MSSM parameter space were discussed, for example in [5],[18]-[20]. Recent results on searches for stop quarks were published in [21].

Assumed theoretical masses of SUSY particles in the cascade (1) and a cross section generated by ISAJET 7.74 [22] are given in Table 2.

Point	$m_{\tilde{g}}$	$m_{\tilde{t}_1}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{l}_R}$	$m_{\tilde{\chi}_1^0}$	$\sigma[\text{pb}]$
SU3	720.16	440.26	223.27	151.46	118.83	19

Table 2: The assumed theoretical masses of sparticles BR and the production cross section σ at the SU3 point. Masses are given in GeV.

A branching ratio for the gluino decay chain (6) at the SU3 point is

$$\tilde{g} \xrightarrow{25.2\%} \tilde{t}_1 \xrightarrow{11.5\%} \tilde{\chi}_2^0 \xrightarrow{11.4\%} \tilde{l}_R \xrightarrow{100\%} \tilde{\chi}_1^0 \Rightarrow 0.33\%.$$

Stop quark \tilde{t}_1 is a mixture of the \tilde{t}_L and \tilde{t}_R states. At the SU3 point, \tilde{t}_1 is the lightest supersymmetric quark because of the renormalization group equation running effect and because \tilde{t}_1 mass is related with the Higgs mass through radiation corrections.

Monte Carlo simulations of SUSY production at model points were performed by the HERWIG 6.510 event generator [23]. The produced events were passed through the AcerDET detector simulation [24], which parametrized the response of a generic detector (LHC detector descriptions can be found in [25], [26]). Samples of 400k SUSY events were used. This approximately corresponds to 20 fb^{-1} of integrated luminosity for the SUSY SU3 point production cross section of 19 pb at 14 TeV.

In order to isolate the chain (6) and to suppress the backgrounds the following selection cuts were applied:

- two isolated opposite-sign same-flavor (OSSF) leptons (not tau leptons) satisfying transverse momentum cuts $p_T(l^\pm) > 20 \text{ GeV}$ and $p_T(l^\mp) > 10 \text{ GeV}$
- two b-tagged jets with $p_T > 50 \text{ GeV}$;
- at least three jets, the hardest satisfying $p_{T1} > 150 \text{ GeV}$, $p_{T2} > 100 \text{ GeV}$, $p_{T3} > 50 \text{ GeV}$;
- total number of jets (including b-tagged jets) $N_{jet} \geq 7$ satisfying $p_T > 10 \text{ GeV}$;
- no τ -tagged jets
- $M_{eff} > 600 \text{ GeV}$ and $E_T^{miss} > 0.2M_{eff}$, where E_T^{miss} is the missing transverse energy and M_{eff} is the scalar sum of the missing transverse energy and the transverse momenta of the four hardest jets;
- lepton invariant mass $50 \text{ GeV} < M_{ll} < 105 \text{ GeV}$.

Top quarks appear both in the signal and in backgrounds. The most important backgrounds for the process (6) are Standard Model $t\bar{t}$ background and SUSY background when $t\bar{t}$ quarks are produced in processes involving SUSY particles but in decay chains different than that in process (6).

After selection cuts were applied, we found 26 signal events corresponding to process (6), 63 SUSY background events containing $t\bar{t}$ quarks and 155 Standard Model $t\bar{t}$ events.

Fig. 2 shows the $t\bar{t}$ invariant mass distribution for 26 signal events remaining after application of the kinematic cuts. At this step, truth information for momenta and energies of $t\bar{t}$ quarks was used. One can see that in this case only two events are outside these kinematic limits which, for process (6), are $q_{min} = 375.1 \text{ GeV}$ and $q_{max} = 496.8 \text{ GeV}$, respectively.

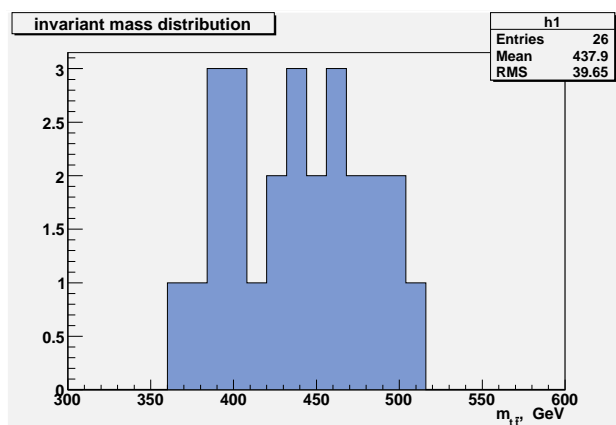


Figure 2: $t\bar{t}$ invariant mass distribution for the signal.

Figs. 3, 4 show the $t\bar{t}$ invariant mass distribution for SUSY background and Standard Model $t\bar{t}$ events. In the last case, most of events are outside kinematic limits (2).

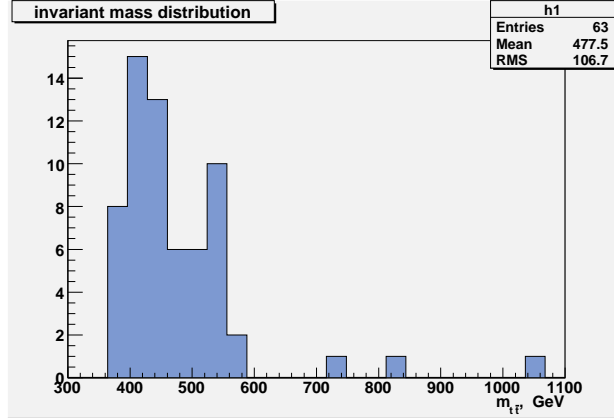


Figure 3: $t\bar{t}$ invariant mass distribution for SUSY background.

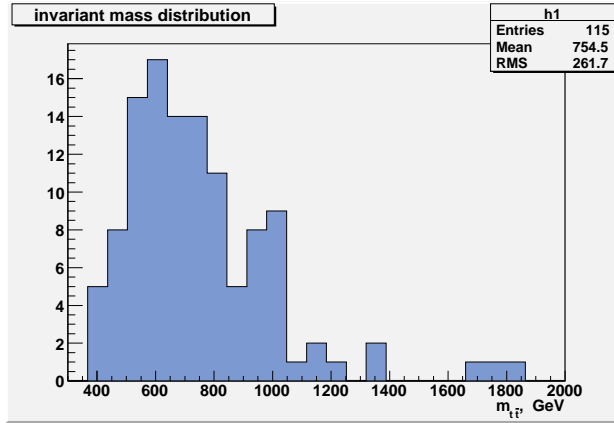


Figure 4: $t\bar{t}$ invariant mass distribution for Standard Model $t\bar{t}$ background.

To suppress Standard Model and SUSY backgrounds an additional cut on events was applied by using upper and lower limits given by Eq.(2). Table 3 shows the number of signal events, SUSY background events and Standard Model $t\bar{t}$ events before and after kinematic cuts (2) were applied.

Total	Signal	SUSY backg.	$t\bar{t}$ backg.
204/75	26/24	63/40	115/11

Table 3: The number of signal and background events before and after application of kinematic cuts (2).

It follows from Table 3 that the number of events surviving selection cuts is reduced significantly after the application of kinematic cuts (2) especially for Standard Model $t\bar{t}$ background events.

These results show that the application of kinematic limits can be effective for background suppression in searches for supersymmetry at the LHC.

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